AD 680168

TECHNICAL MEMORANDUM NO. 4-79

SPIRAL GENERATION OF BUILDING SHELLS FOR MILITARY CONSTRUCTION

by

A.N. Collishaw
R.D. Graham

DEC 17 1968

November 1968

DEPARTMENT OF THE ARMY
OHIO RIVER DIVISION LABORATORIES, CORPS OF ENGINEERS
CINCINNATI, OHIO 45227

30

Technical Memorandum No. 4-79

SPIRAL GENERATION OF BUILDING SHELLS FOR MILITARY CONSTRUCTION

by

A. N. Collishaw

R. D. Graham

November 1968

DEPARTMENT OF THE ARMY
Ohio River Division Laboratories, Corps of Engineers
Cincinnati, Ohio 45227

SUMMARY

The purpose of this report is to document immediate and potential applications of the spiral generation construction process to Military Construction. Costs are shown for buildings constructed by fabricating shell structures in a spiral fashion using factory processed rigid plastic foam board, and costs are shown for Military Construction. An economic study based on such costs indicates that it is not economical to use plastic foam board shells except in limited applications, such as a Cold Storage or Freezer Facility or large (100-ft) open span construction.

There are potential savings of shipping weight, shipping volume and construction time, when comparing Foam-in-Place shell structures (an undeveloped process) to prefabricated metal buildings. These potential savings are important logistic considerations for emergency overseas construction. The following estimates represent potential savings of Foam-in-Place construction of shell structures as a percentage of prefabricated metal buildings: cost 15-70%; shipping weight 50-65%; shipping volume 60-75%; erection time, man hours 55-85%. The actual savings will vary with the specific application.

PREFACE

This investigation was authorized by the work outlined in the research and technology resume, 6.21.44.01.1 4A024401A89102, "Materials for Permanent Construction."

This report was prepared by Messrs. A. N. Collishaw and R. D. Graham.

Messrs. F. M. Mellinger and R. L. Hutchinson were Director and Assistant Director, respectively, of the Ohio River Division Laboratories during this investigation; Mr. E. A. Lotz was Chief of the Construction Engineering Laboratory.

BLANK PAGE

CONTENTS

CONVERSION FACTORS

BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
inches	2.54	centimeters
feet	0.3048	meters
square feet	0.092903	square meters
cubic feet	0.0283168	cubic meters
pounds	0.45359237	kilograms
short tons (2000 lbs)	907.185	kilograms

SPIRAL GENERATION OF BUILDING MATERIALS

FOR

MILITARY CONSTRUCTION

PART I: INTRODUCTION

Purpose

1. The purpose of this report is to document immediate and potential applications of the spiral generation construction process to Military Construction. Included are permanent, semi-permanent and temporary construction. The secondary purpose is to provide guidance for additional research.

Background

2. With exceptions, very little has been accomplished by the building construction industry to exploit methods used by manufacturers to increase production and reduce costs. The area that should be explored is the automation of construction techniques - or supplementing man with machine. Although machines have made man's work easier, bricks are still laid by hand, boards are still measured, sawed and nailed into place by hand, and structural elements are bolted or welded into place by hand.

3. One exception is "Spiral Generation."* Spiral Generation is a method of enclosing space by means of a machine process. After a proper foundation has been provided by conventional means, a structurally sound, hemispherically shaped building shell, enclosing 5000 sq ft** of floor space, can be produced in approximately 12 to 16 hours with a crew of 3 or 4. Additional manhours and material must be used to provide a weatherproof coating. The degree of permanency and the particular application determines the additional treatment required.

---

*Spiral Generation is the trademark of the Dow Chemical Company.

** A table of factors for converting British units of measure to metric units is presented on page viii.

PART II: STATE OF THE ART

4. The basic material used in the Spiral Generation process is polystyrene foam plastic board. Polystyrene is a thermoplastic material; it softens, becomes plastic, when heated. This characteristic is used to bond one board to another. After the base course is secured to the foundation, the next layer is heat welded to the base course by the welding head of the equipment. The welding head also controls the placement of the board and places it in the desired pre-determined position. The welding head rides along the length of a boom. The boom rotates in a circle, and therefore, the plan view structure is circular. The profile of a cross-section of the elevation of the resulting structure may be hemispherical, or a section, or cap of a sphere. The equipment is capable of generating other basic profiles; however, only spherically shaped profiles have been produced to date.

5. The examples of the use of the "Spiral Generation" technique, presented in the table on page 17, were chosen to illustrate a wide variety of uses. Included are industrial, residential, commercial and public applications. The exterior finishes include:

a. Sand filled latex paint, applied directly to the foam. This is a relatively inexpensive finishing technique. The paint protects the foam from the degrading effects of exposure to ultraviolet rays from the sun.

b. Latex modified stucco, reinforced with lath. The stucco is covered with a nylon reinforced chlorinated polyethylene membrane, 20 mils thick coated with 12 mils of neoprene hypalon. The stucco serves as a structural part of the shell, and protects the foam from fire hazards. The membrane waterproofs the dome. Stucco has been used with chicken wire and expanded metal mesh reinforcement.

c. The plastic foam has been covered with gunite and steel reinforcement. The foam acts as the form and also as an insulation. The gunite is covered with a waterproof membrane.

PART III: MILITARY CONSTRUCTION APPLICATIONS OF SPIRAL GENERATION

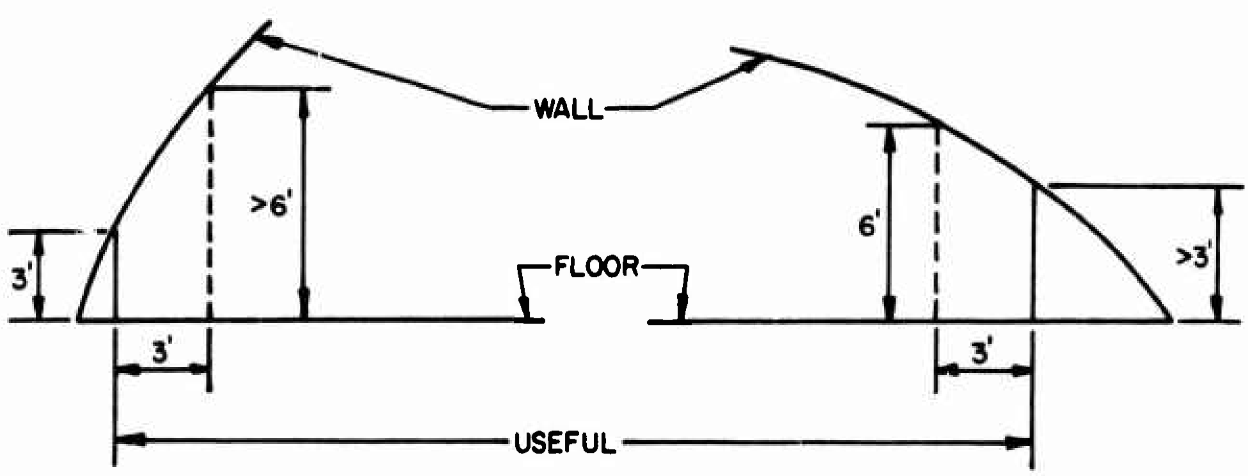
Immediate Application

6. The examples of civilian use of Spiral Generation in the table on page 17, indicate that it is technically feasible to construct building shells. An analogy can be drawn between the civil uses and prospective uses for Military Construction. The following types of buildings, including up to four stories, could be programmed:

- administration buildings
- auditoriums
- barracks
- bachelor officer quarters
- chapels
- dental clinics
- dependents schools
- dispensaries
- family housing
- hospitals
- tactical equipment shops
- training buildings
- operations buildings
- sewerage treatment plants
- warehouses

7. The listed buildings could be designed to be temporary, semi-permanent or permanent. There would be some minor changes in foundation design and shell design (wall thickness) since the materials used in temporary buildings are stressed nearer the ultimate than are materials used in permanent buildings. The major change between temporary and permanent classifications would be the interior and exterior surface treatments.

8. Since the floor area under a sloping wall is not entirely useful, it is necessary to define "useful floor area". The following definitions were chosen arbitrarily by the authors: Floor space under a sloping wall is considered useful as long as it can be reached, providing the wall is at least 3 ft high. In general, the area 3 ft beyond a sloping wall 6 ft high is accessible. Although the areas beyond the 3-ft limits may be accessible, for practical purposes, they are not considered useful. The sketches below are used to illustrate the definitions.



The sketch on the left indicates the floor space is useful except for the part which has 3 ft or less wall height. The sketch on the right indicates the floor space is useful 3 ft beyond a point projected from a 6-ft wall height.

Typical Useful Floor Areas

No. Stories	Useful Floor Area (sq ft)	Diameter ft	Shape	Height ft
1	3, 400	70	LP*	27
1	4, 600	80	LP	31
1	5, 800	90	LP	33
1	7, 400	100	LP	37
2	5, 700	70	LP	27
2	8, 800	80	LP	31
2	9, 350	90	LP	31
3	8, 650	70	Hemisphere	35
3	9, 500	80	LP	31
3	12, 000	80	Hemisphere	40
3	13, 350	90	LP	36
4	13, 000	80	Hemisphere	40
4	18, 550	90	Hemisphere	45
4	21, 900	100	LP	45
4	25, 500	100	Hemisphere	50
5**	26, 750	100	Hemisphere	50

* Low Profile is the designation assigned to a spherical shape where the height is less than 1/2 the diameter.

** Note the small gain of floor area of the five story over the four story building; 100 feet is the maximum practical diameter to date. The capability of existing equipment may be extended in the future.

Economics

9. The Spiral Generation construction technique is economically competitive with conventional materials and techniques for large open spans (80 to 100 ft) and aesthetically appealing public or commercial buildings. Military Construction does not have broad application for large spans, and its type of construction is usually considered purely functional or austere.

10. The following costs are given for two of the structures listed in the table on page 17, "Typical Applications of Spiral Generation." The costs for the Women's Medical Clinic were supplied by the architect, E. H. Brenner. The clinic consists of a group of connected hemispherical dome structures. There are four 26-ft diameter domes, a 36-ft diameter, a 33-ft diameter, and a 44-ft diameter dome. The 44-ft dome has a mezzanine and a basement. The area is 8210 sq ft at a cost of $10.70/sq ft for the structure only.

11. The costs for the Roeper Country and Day School, Bloomfield Hills, Michigan, were supplied by Mr. Thomas J. Lucas of Glen Paulsen and Associates, Architects. The total building area is 17,000 sq ft. Of this, 10,380 sq ft are in two 67-ft diameter and six 33-ft diameter domes. The domes are connected by areas with vertical walls and flat roofs.

Cost of complete structure	$14.60/sq ft
Mechanical and Electrical	7.70/sq ft
Air Conditioning	1.25/sq ft
Total Cost	$23.55/sq ft

Cost of an Elementary School in the Detroit area by the same architect was $24.00/sq ft without air conditioning. The cost including air conditioning in this conventional construction was estimated to be $2.00/sq ft.* As a comparison, a three story, concrete frame, concrete floor barracks with block walls and brick veneer costs in the order of $17/sq ft, without air conditioning.

12. As part of this study, an estimate was made of a Battalion (vehicle) Repair Shop. The cost was estimated based on the unit costs used for the Government Estimate of a Battalion Repair Shop for Fort Knox, Kentucky. The one story, rectangular plan, steel frame, concrete block exterior walled building cost $108,900 for the building shell, not including mechanical and electrical work. The estimated cost for the same space in the circular dome plan was $133,700, or 23% more.

* Letter, by H. S. Smith, dated April 9, 1968.

13. A second estimate was made, based on the construction of a Cold Storage Facility (refrigerated and frozen food warehouse), Westover Air Force Base, Massachusetts. This estimate showed a 7% savings in the costs of the building shell, in favor of the circular plan over the conventional rectangular plan. The overall savings was 4.5% when the mechanical and electrical costs were added. The cold storage facilities were chosen as the basis for an estimate because this particular application takes advantage of the foam plastics insulation characteristics as well as structural qualities. The estimates indicate that there are limited applications for "Spiral Generation" in Military Construction based purely on economics.

Future Application

14. Foam-in-Place techniques are being investigated by the Army. The foam-in-place technique of fabricating a foam plastic shell structure is similar to Spiral Generation. The major difference between the foam-in-place technique and Spiral Generation is the state of the materials. Spiral Generation uses light bulky foam plastic board stock at a density of approximately 2 lbs/cu ft. The foam-in-place materials are transported in liquid form with a density in the order of 75 lbs/cu ft. The materials are metered, mixed and foamed in place at the construction site. The density of the foamed material is approximately 4 lbs/cu ft, which is equivalent to the bulk saving ratio of materials alone of approximately 18/1.

15. Perhaps the main reasons for considering foam-in-place techniques are the potential savings of shipping volume, weight, and construction time for Military Construction Overseas. The following data is presented so that a comparison can be made between costs, shipping cube, shipping weight, and erection time of metal prefabricated buildings and foam-in-place shell structures. A common base of 10,000 sq ft of floor area was used.

COMPARISON I

Prefabricated Building System (1)

Type II (warehouse) w/o floor

FSN - 5410-633-4358

Specification: MIL-B-52055

Utilization: warehouse (or shop)

Size: 40 ft x 100 ft

Area: 4,000 sq ft

Shell Structure, Dome Shaped (2)

w/o floor

Site fabricated

Utilization: warehouse

Size: 80 ft diam x 34 ft high

Area: 5,050 sq ft

	Based on 10,000 sq ft Floor Area		Dome Savings (% of Prefab)
	Prefab	Dome	
Estimated cost, materials (3)	\$30,000	\$11,000	63
Estimated cost, erection Labor @ \$4.00/hr (3)	\$10,000	\$ 1,360	86
Total estimated cost	\$40,000	\$12,300	69
Net weight, ton	30.0	--	--
Gross weight, ton (4)	38.5	15.0	64
Gross shipping volume (4)	2,140	530	75
Erection time, manhours	2,500	340	86

Note:
(1) "Reference Manual on Shelters" published by U. S. Army Materiel Command, January 1967, page 55.

(2) See Appendix for the calculations made to support these figures.

(3) No labor or material cost or time was allowed for grading or floor.

(4) Estimated by the authors.

COMPARISON II

Building, Prefabricated, Steel (1)	Shell Structure, Dome Shaped (2)
Vertical Wall, with floor	Site fabricated with prefabricated doors and floor
FSN - 5410-025-3930	
Specifications: MIL-B-12568 (CE)	
Utilization: General purpose	Utilization: General purpose
Size: 20 ft x 48 ft	Size: 80 ft diam x 31 ft high
Area: 960 sq ft	Useful floor area: 4, 600 sq ft (3)

	Based on 10, 000 sq ft Floor Area		Dome Savings (% of Prefab)
	Prefab	Dome	
Estimated cost, materials	$28, 000	$26, 000	6
Estimated cost, Labor @ $4.00/hr	$ 8, 500	$ 3, 800	55
Total cost	$36, 500	$30, 100	14
Gross weight, ton	63.5	31.4	50
Gross shipping volume, cu ft	3, 530	1, 410	60
Erection time, manhours	2, 140	950	55
Foundation requirement	Field Expedient	Intregral w/system	--

Note: (1) "Reference Manual on Shelters" published by U. S. Army Materiel Command, January 1967, page 61

(2) See Appendix for the calculations made to support these figures.

(3) "Useful Floor Area" is defined in Part III, paragraph 8.

PART IV: STRUCTURAL DESIGN CONSIDERATIONS

16. To date, many circular domes have been built as roofs of structures. These have ranged from the dome of St. Peter's Cathedral in Rome which spans 132 ft with an average thickness of about 10 ft, to modern reinforced concrete domes which will span 132 ft with a shell thickness of about 2-1/2 inches (1)*. The design of modern reinforced domes is generally based on membrane theory analysis. According to this theory, the shell is so thin it will not resist bending but is designed to resist loading through compression and tensile stresses. Because thin shells basically act according to membrane theory, they are very efficient providing they are not so thin that buckling occurs.

17. As stated, many domes have been designed according to membrane theory and although often no buckling analysis was made, the structures have performed well because of the healthy safety factor used. More ambitious analyses which include buckling calculations and tests of models show that buckling is the critical mode of failure of thin homogeneous shells (2, 3, 4, 5).

18. Two of the analytical methods of determining critical buckling loads on circular shell structures may be called the differential equation and the energy methods. The differential equation method consists of equating the differential equations of the loads, displacements, and strains. The energy method involves equating the sum of the strain energy and external work. Both of these approaches result in an equation of the form $P_{cr} = KE\,(t/R)^2$ in which P_{cr} is the critical uniform load, E is the modulus of elasticity of the shell material, t is the thickness of the shell, R is the radius of the shell, and K is a constant which has been derived by Flugge (6) as $K = 2/(3\,(1-\mu^2))^{1/2}$. The symbol μ is Poisson's ratio.

19. Various derivations and tests of models have resulted in wide variations in the values to be assigned to K. Although much work can be found on attempts to determine this value, tests on shells indicate that variances in edge conditions shell geometry, and shell materials can result in wide variances in the value of K. Tests performed by Dow Chemical Company (2) on styrofoam spherical caps supported the K value as derived by Flugge.

20. Since buckling has been shown to be the critical mode of failure of these thin shells, and since the buckling load is proportional to the square of the thickness to radius ratio, much attention has been given to improving the effective thickness.

---

*Parenthetic numbers indicate references.

The effective thickness with respect to buckling can be increased by adding stiffeners to the shell, or by designing the shell with a sandwich or double-walled section.

21. A sandwich section with a low density core and walls or skins with a relatively high modulus of elasticity will provide the most efficient cross section in use. The proper combination of skins and core results in a shell buckling strength equal to the direct stress strength. This type of construction is particularly conducive to the development of foam-in-place construction.

22. Spirally generated styrofoam domes presently being built are designed according to simple equations derived for critical loadings under direct stress and buckling criteria. These designs have been verified by model tests of styrofoam domes and by the performance of the structure themselves. The styrofoam structures can be classified structurally in three categories as follows:

a. In the first category, the styrofoam dome is constructed and then used as a form on which to apply concrete and reinforcing to build a reinforced concrete shell. In this case, the styrofoam dome is designed for the construction loads and the concrete dome is designed as the final structure which supports the foam, interior applications such as plaster, and design loads such as snow. The structure is basically a concrete dome constructed with a foam form which is left in place to serve as an excellent insulator and as a medium upon which interior finishes may be applied.

b. In the second category, the foam dome remains the basic structure but reinforced surface treatments act compositely with the foam shell.

c. The third category structure is simply a foam structure which is treated with a protective coating such as paint.

23. In each of these cases, the structural analysis has been based on a dome designed without openings and with edges restrained. When openings have been cut, they have been reinforced to resist the forces which would have been resisted by the removed material.

24. The design of the foundations of styrofoam domes presents a problem somewhat different from that experienced in conventional foundation design. These structures are very lightweight and of such a shape that winds produce an uplift force (7) which must be resisted by the foundation. As a result, the major concern in the foundation design is the "hold down" capability while concern for the resistance of the gravity load is minimal.

25. Existing design analyses of styrofoam domes do not include the effects of openings and variations in edge conditions although several have been constructed with rather severe openings. The use of the present methods of analysis has resulted in efficient structures. However, greater efficiency could be gained through the use of sandwich shell design and more rigorous structural analysis of the effects of openings and edge conditions.

26. The aerospace age has fostered many developments in the methods of analysis of shell structures which can be modified to apply to building structures. Aerospace laminated reinforced plastic domes have been analyzed for static, dynamic and temperature stresses both in the elastic and inelastic ranges. Computer programs are available for these analyses by the finite element and discrete element methods (8, 9, 11).

PART V: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

27. The cost data presented indicates that conventional construction techniques are more economical than the Spiral Generation for most Military Construction within the United States. There are limited exceptions, such as Cold Storage or Freezer Facilities or large (100 ft) open span construction.

28. The data presented for the foam-in-place of building shells indicates that there are potential savings of shipping weight and volume, and construction time. The savings favor foam-in-place building shells over prefabricated metal buildings for emergency Military Construction overseas. The savings are estimated to be in the following range:

Cost (Labor and Materials)	15	-	70%
Shipping Weight	50	-	65%
Shipping Volume	60	-	75%
Erection Time (manhours)	55	-	85%

The actual savings will vary with the specific application.

29. The discussion presented on structural design considerations indicates that foam-in-place sandwich shell would be a more efficient design than the present Spiral Generation homogeneous shell. The discussion also indicates that additional structural analysis, possibly by computer methods, is required as part of the development of the foam-in-place process.

Recommendations

30. It is recommended that further investigational work on Spiral Generation of structures for Military Construction be deferred. The Spiral Generation technique can be applied to special economical applications, such as food freezers and cold storage warehouses, without additional research work.

31. It is recommended that the development of the foam-in-place concept be continued, considering the potential logistic and cost advantages.

32. It is recommended that the Army research and development program of foam-in-place shell structures include the use of computer design techniques, and the testing of large scale and full size structures. This work would be used to provide the necessary criteria for a standard design manual for foam-in-place shell structures.

REFERENCES

1. Pfuger, A., "Elementary Statics of Shells," McGraw-Hill Book Company, Incorporated, 1961

2. Smith, H., "Private Communication," Dow Chemical Company, 1966

3. Little, William A., "Reliability of Shell Buckling Predictions," Research Monograph No. 25, The MIT Press, Cambridge, Massachusetts, 1964

4. Buchert, Kenneth P., "Buckling of Doubly Curved Orthotropic Shells," University of Missouri, Engineering Experiment Station, Columbia, Missouri, November 1965

5. Muldoon, R. A., "Dynamic Buckling of Space Frame Radome Models," Support By Groups 76 and 71, MIT Lincoln Laboratory, Paper Reproduced by Armed Services Technical Information Agency, 15 February 1962

6. Flugge, W., "Stresses in Shells," Springer-Verlag, Berlin, 1960

7. Task Committee on Wind Forces of the Committee on Loads and Stresses of the Structural Division. "Wind Forces on Structures," Paper No. 3269, American Society of Civil Engineers Transactions, Vol. 126, Part II, 1961

8. Massard, J. M., "General Inelastic Response of Layered Shells," Lockheed Missiles and Space Company, September 1966

9. Percy, John H., et. al., "Sabor I and Sabor III, A Fortran Program for the Linear Elastic Analysis of Thin Shells of Revolution Under Axisymmetric Loading by Using the Matrix Displacement Methods," Massachusetts Institute of Technology, Cambridge, Massachusetts, April and May 1965

10. Thiel, Richards, Dowell, Cakmak, "Application of the Finite Element Method to the Sonar Dome," General Technology Corporation, Lawrenceville, New Jersey, April 1967

BIBLIOGRAPHY

1. Baumgardner, Collishaw, Krohn, Schartz, "Feasibility Study, Mobile Plastic Fabrication Unit TR 66-011," Engineering Division, Military Construction, Department of the Army, Office of the Chief of Engineers, Washington, D. C., 1 July 1966

2. Gerald, Becker, "Handbook of Structural Stability, Part III - Buckling of Curved Plates and Shells," National Advisory Committee for Aeronautics Technical Note 3783, Washington, D. C., August 1957

3. Grafton, Green, Jones, Strome, Weikel, "Application of the Stiffness Method to the Analysis of Shell Structures," The Boeing Company Report No. D2-24115-1, February 1966

4. Heger, Chambers, Dietz, "On the Use of Plastics and Other Composite Materials for Shell Roof Structures," Professional Paper P62-10 Department of Civil Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts, October 1962

5. Petyt, M., "The Application of Finite Element Techniques to Plate and Shell Problems," University of Southampton, Hampshire, England, February 1965

6. Portland Cement Association, "Design of Circular Domes," Structural and Railways Bureau, PCA, Chicago, Illinois

7. Stengard, R. A., "Properties of Rigid Urethane Foams," Elastomer Chemicals Department, DuPont De Nemours and Company (Inc.), Wilmington, Delaware, June 1963

8. Thiel, Richards, Dowell, Cakmak, "Application of the Finite Element Method to the Sonar Dome," General Technology Corporation, Lawrenceville, New Jersey

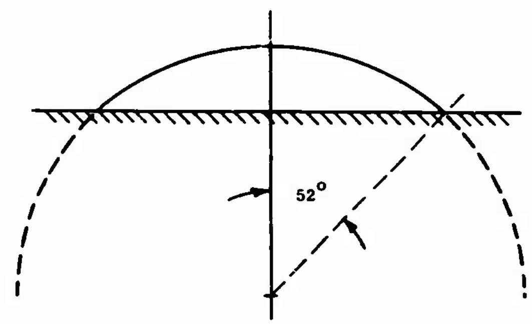
9. U. S. Department of Defense, "Composite Construction for Aircraft Part III - Design Procedures," Mil-Handbook 23, Superintendent of Documents, U. S. Government Printing Office, Washington, D. C., November 1961

10. VOL'MIR A. S., "A Translation of Flexible Plates and Shells," Technical Report AFFDL-TR 66-216, Department of Engineering Science and Mechanics, University of Florida

TYPICAL APPLICATIONS OF SPIRAL GENERATION

Name/Address	Owner/Architect	Application	Date	No.	Size	Shape	Foam Thickness	Interior Finish	Exterior Finish
Trickling Filter Covers Midland, Michigan	City of Midland, Michigan	Industrial	1964 1966	2 2	80-ft.	52^o LP	8-inch	None	Sand Filled Latex Paint
Brine Tank Covers Freeport, Texas	Dow Chemical Company	Industrial	1966	2	90-ft.	52^o LP	8-inch	None	Acrylic Latex Paint, Glass Cloth Reinforced Insulation Mastic
Holding Freezers Marshall, Minnesota	Swift and Company	Industrial	1966	2	92-ft.	52^o LP	8-inch	Two Coats Portland Cement Mortar, Chicken Wire Reinforced Plaster	3/4 inch Latex Modified Stucco, Lath Reinforced Plus 20 mil Membrane Nylon Reinforced Plus 12 mil White Hypalon
Residence Ionia, Michigan	Robert Hefner	Residence	1966	1	35-ft.	Hemisphere	4-inch	Plaster and Chicken Wire Reinforced	3/4 inch Latex Modified Stucco, Chicken Wire Reinforced, Plus Butyl Paint Plus Neoprene Hypalon
Office and Lab Dalton, Georgia	Dow Chemical Company	Commercial	1966	2	42-ft. 45-ft.	22^o LP	6-inch	Chicken Wire Reinforced 3 Coat Gypsum Plaster	4-6 inch Steel Reinforced Concrete Plus 20 mil Hypalon
Woman's Clinic	Professional Center, Incorporated E. H. Brenner, A.I.A.	Commercial	1965	7	24-ft. 42-ft.	Hemisphere	4 to 6 inch	Three Coats Soft Acoustical Plaster Chicken Wire Reinforced	Reinforced Gunite Arches Plus 1 inch Reinforced Gunite Concrete Plus Neoprene Hypalon Roofing
Roeper City and Country School Bloomfield Hills Michigan	City of Bloomfield Hills Glen Paulsen and Associates, Incorporated	Public	1967	8	6-33 ft. 2-67 ft.	LP	4-inch 6-inch	Wire Reinforced Plaster	Expanded Metal Lath 3/4 inch Latex Modified Stucco

*LP = Low Profile, that is, less than a Hemisphere. The angle given is the central angle as illustrated by the sketch.



BLANK PAGE

APPENDIX

1. The cost of a foam-in-place dome, with prefabricated floor and doors, can be estimated based on the following assumptions. Note that the accuracy of the estimate will be only as good as the assumptions:

   a. Foam shell costs $1.00 per sq ft of surface area. *

   b. The unit (sq ft) cost of the prefabricated floor and doors is proportional to the cost of the prefabricated buildings cited in paragraph 15, Comparison II. **

2. The estimated unit cost of the prefabricated floor and doors is determined by the following calculations. Given prefabricated building data:

Size: 20 x 48 x 10 ft high

Shipping weight, ton. . . .	6.1
Shipping volume, cu ft . . .	338.6
Erection time, manhours. .	205
Cost	$2,700

3. The total surface of the 20' x 48' metal building is 2 x (20 x 48 + 10 x 48 + 10 x 20) = 3280 sq ft. The unit cost per sq ft surface area is: $2700/3280 = $0.823/sq ft. The total dome floor area $= \pi r^2 = \pi (39.5)^2 =$ 4,901 sq ft

4. This figure is used to compute the cost, shipping volume, and shipping weight and erection time of the prefabricated floor and door portion of the dome building.

---

* This figure is an approximate average of proposals submitted to the Ohio River Division Laboratories.

** Source of cost of prefabricated buildings: "Reference Manual on Shelters," U. S. Army Materiel Command, January 1967, pg 61.

5. The unit volume and weight of the prefabricated floor and doors may be estimated by assuming that they are a proportion of the area of the floor/the total surface area of the prefab building. Therefore, the weight of the dome floor is:

$$\frac{6.1 \text{ ton}}{3280 \text{ sq ft}} = .00185 \text{ ton/sq ft and } .00185 \times 4901 = 9.1 \text{ ton}$$

6. The unit shipping volume of the floor and door is:

$$\frac{1}{3280} \times 338.5 = .1032 \text{ ft/sq ft}$$

The shipping volume of the floor and door is:

$$.1032 \times 4901 = 506 \text{ cu ft}$$

7. The unit floor erection time is:

$$\frac{1}{3280} \times 205 = .0625 \text{ manhours/sq ft}$$

The dome floor erection time is:

$$.0625 \times 4901 = 306.3 \text{ manhours}$$

approximately 308 manhours

8. The cost of the dome floor and door may be estimated as:

4901 sq ft x $.823/sq ft = $4,033.52

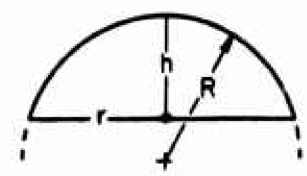
approximately $4050 for the floor and doors

9. Computations for the solution of dome surface and volume (of shell).

Given: 80 ft outside diam, 31 ft outside height and 4-inch wall thickness

$S = 2\pi R h$

where:



S = Surface area

R = Spherical radius

h = Height of spherical section, 31 ft

r = Outside of radius, at ground, 40 ft

$$R = \frac{r^2 + h^2}{2h}$$

$$R = \frac{(40)^2 + (31)^2}{2 \times 31} = 41.3 \text{ ft}$$

$$S = 2\ (41.3)\ 31 = 8044 \text{ sq ft}$$

Volume (as foamed) = 8044 sq ft x 4/12 ft = 2681 cu ft

If the "as foamed" density is assumed to be 4 lbs/cu ft and the "shipping density" is assumed to be 75/cu ft then

$$\text{the shipping volume per dome} = \frac{2681 \text{ cu ft} \times 4 \text{ lbs/cu ft}}{75 \text{ lbs/cu ft}} = 144 \text{ cu ft}$$

10. The shipping weight per dome = 144 cu ft x 75 lbs/cu ft
= 10, 725 lbs, or approximately 5. 3 ton

11. The dome erection time may be estimated as follows:

set up equipment - 3 men - 4 hours	=	12
foam dome - 3 men - 36 hours	=	108
take down equipment - 3 men - 4 hours	=	12
Total Hours	=	132

12. Cost of the foam-in-place shell is estimated as $1.00/sq ft of the surface area.

$1.00 x 8044 sq ft = $8,044 - approximately $8,050

Totals, Shell plus Floor and Doors

Shipping weight, ton	9.1	+5.3	=	14.4
Shipping volume, cu ft	506	+144	=	650
Erection time, manhours	308	+132	=	440
Cost, materials	4050	+8050	=	$12,100

Cost, labor, 440 hr x $4.00/hr . . . . $ 1,760

Cost, Total $13,860

The figures above are based on 4600 sq ft of useful floor area. These figures were modified by multiplying by $\frac{10,000}{4,600}$ to adjust to the base of 10,000 sq ft in Comparison II.

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1 ORIGINATING ACTIVITY (Corporate author) DEPARTMENT OF THE ARMY Ohio River Division Laboratories, Corps of Engineers	2a REPORT SECURITY CLASSIFICATION Unclassified 2b GROUP

3 REPORT TITLE

SPIRAL GENERATION OF BUILDING SHELLS
FOR
MILITARY CONSTRUCTION

4 DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final Technical Memorandum

5 AUTHOR(S) (Last name, first name, initial)

Collishaw, A. N.
Graham, R. D.

6 REPORT DATE	7a TOTAL NO OF PAGES	7b NO OF REFS
November 1968	22	10

8a CONTRACT OR GRANT NO. b. PROJECT NO. c d	9a ORIGINATOR'S REPORT NUMBER(S) TM No. 4-79 9b OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10 AVAILABILITY/LIMITATION NOTICES

This document has been approved for public release and sale; its distribution is unlimited.

11 SUPPLEMENTARY NOTES	12 SPONSORING MILITARY ACTIVITY
	DEPARTMENT OF THE ARMY

13 ABSTRACT

The purpose of this report is to document immediate and potential applications of the spiral generation construction process to Military Construction. Costs are shown for buildings constructed by fabricating shell structures in a spiral fashion using factory processed rigid plastic foam board, and costs are shown for Military Construction. An economic study based on such costs indicates that it is not economical to use plastic foam board shells except in limited applications, such as a Cold Storage or Freezer Facility or large (100-ft) open span construction.

There are potential savings of shipping weight, shipping volume and construction time, when comparing Foam-in-Place shell structures (an undeveloped process) to prefabricated metal buildings. These potential savings are important logistic considerations for emergency overseas construction. The following estimates represent potential savings of Foam-in-Place construction of shell structures as a percentage of prefabricated metal buildings: cost 15-70%; shipping weight 50-65%; shipping volume 60-75%; erection time, manhours 55-85%. The actual savings will vary with the specifi application.

DD FORM 1 JAN 64 1473

Unclassified
Security Classification

Unclassified

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Buildings						
Buildings and Prefabrication						
Cellular Plastics						
Structural Plastics						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2a. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7a. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8a. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through
________________."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through
________________."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through
________________."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS)*, *(S)*, *(C)*, or *(U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.

Unclassified

Security Classification